MADROÑO, Vol. 46, No. 2, pp. 80–87, 1999

REVISITING NATIVE *PINUS RADIATA* FORESTS AFTER TWENTY-NINE YEARS

KEITH L. WHITE
Natural and Applied Sciences, University of Wisconsin-Green Bay
Green Bay, WI 54311-7001

ABSTRACT

Repeat sampling of 19 native *Pinus radiata* D. Don stands, each about one ha, was conducted after a 28–29 year interval. Tree density decreased from 636 per ha in 1965–1966 to 460 in 1994, probably due to mortality of young *P. radiata.*

In these unburned stands, tree seedling densities were low for all species, and similar for both sample times although the density by stand was variable—from 11 to 790 per ha in 1965–1966 and 15 to 986 per ha in 1994. Two-thirds of the tree seedlings sampled were *Quercus agrifolia* Nee, easily growing under the *P. radiata* canopies.

Tree sapling densities were also low, averaging 177 per ha in 1965–1966 and 99 in 1994. In 1965–1966 only 58% of the saplings were *P. radiata,* and in 1994 only 50% were *P. radiata.* The rest, except for a single *Arbutus menziesii* Pursh, were *Q. agrifolia,* having tolerated heavy deer browsing as seedlings for years and finally producing a central stem emerging as a sapling.

The stands reflect a sequence of maturation, from dense *P. radiata* poles to sparse large *P. radiata* trees with small *Q. agrifolia* trees below. Stands that were logged in the past (decades prior to 1965–1966) had high numbers of *Q. agrifolia* (seedlings, saplings and trees) below those few large *P. radiata* trees left (for unknown reasons) after logging.

Of the 38 stands of *P. radiata* sampled in 1965–1966 on the Monterey Peninsula, 12 had been seriously modified by human activity by 1994.

There have been many studies examining the management of *Pinus radiata* D. Don forests, but mostly of plantations and especially in Australia and New Zealand (Scott 1960; Pert 1963). Few reports describe the natural *P. radiata* forests in California (Roy 1966; McDonald and Laacke 1990), and there are only brief comments in these reports that refer to changes in the forests over time. This study adds to the sparse information on temporal variation in the natural *P. radiata* forests by examining changes in a series of stands first studied in 1965–1966 (Vogl et al. 1977) and then restudied in 1994 (this report).

Stand Selection in 1965–1966. In the early summers of 1965 and 1966 I sampled the trees, tree saplings and tree seedlings, shrubs and forbs in 48 approximately one ha natural *P. radiata* stands in California (Vogl et al. 1977). The 48 stands were scattered over the natural range of this species and included four near Año Nuevo Point, six near Cambria, and 38 on the Monterey Peninsula. My goal in 1965–1966 was to provide a quantitative description of the vegetation in the natural *P. radiata* forests in California. At that time an attempt to establish an 800 ha State Monterey Pines Park on the Monterey Peninsula was failing. With such a large block of the natural *P. radiata* forest at risk of development, it seemed appropriate to obtain some measure of the relationship between ground flora and canopy in the natural forest before more widespread modification occurred. Since then, fortunately, Jacks Peak Regional Park was established on the Peninsula embracing 212 ha of mostly natural *P. radiata* forest. According to Deghi et al. (1995) 42% (1174 ha) of the *P. radiata* forest at Monterey is now permanently protected.

The native stands of *P. radiata* were heavily logged for their high quality timber since the time of settlement, and were also grazed and subjected to fires. Thus the use of "natural" in describing a particular stand has its critics. At the least, my sample stands in 1965–1966 excluded the urban forests (Deghi et al. 1995), the forest remnants on golf courses and in housing developments, and planted stands. Selection of a stand was based on apparent dominance by *P. radiata* trees. Those stands selected represented a range of previous and existing conditions, including logging, grazing and burning, variation in elevation and distance from the ocean, and variation in soils. The natural *P. radiata* forests occur over a variety of geological parent materials, and on soils from four orders embracing thirteen soil series (McDonald and Laacke 1990; Deghi et al. 1995). Some of the sample stands at Monterey occurred on the marine terraces mapped by Cylinder (1995), but most occurred further inland on Santa Lucia and Sheridan soils. Because of the range of conditions tolerated in stand selection, some stands sampled were not dominated by *P. radiata*; this occurred in stands that were logged in the past and had numerous *Quercus agrifolia* Nee trees.

I did not sample any stands in the Huckleberry Hill area at Monterey where *P. radiata* occurs with *Cupressus macrocarpa* Gordon, *C. goveniana* Gordon and *P. muricata* D. Don.

Stand Selection in 1994. In February of 1994, I attempted to re-sample the 38 stands of *P. radiata* on the Monterey Peninsula. Notes entered on U.S. Geological Survey quadrangle maps used in the original study provided locations of the stands. Some of the stands occurred on steep terrain in undeveloped areas without unique constructed landmarks and as a consequence four stands could not be re-located. None of these four stands were absent because of cutting or fire. One other stand could not be re-located because an identifying road had been eliminated. In addition, three stands were partially cut for housing developments, three burned completely in the 1987 Del Monte Properties (once Pacific Improvement Co., then Del Monte Properties Co., and now Pebble Beach Properties) wildfire, and one was clear-cut for a golf course.

Five stands appeared partially logged, since larger dbh trees present in 1965–1966 were missing in 1994; stumps and firewood blocks were present in one of these stands in 1994 but no dead trunks or remnants of dead trunks were present in any. A broad range of conditions was embraced by the sampled stands in 1965–1966, including previous logging, but my goal in 1994 was to assess any natural changes over the intervening 28–29 yr and so these five stands apparently logged since 1965–1966 were rejected.

In two other stands, tree dbh comparisons between 1965–1966 and 1994 indicated a mis-match of location since the larger dbh of trees in 1994 could not possibly have been attained in the 28–29 yr interval.

Thus, with 12 stands modified by cutting or fire since 1965–1966, and seven stands not accurately relocated, sample data from only 19 of the original 38 stands at Monterey were used in this study. Nine of the 19 were initially sampled in 1965, while the other ten were initially sampled in 1966.

METHODS

In each of the 19 stands I sampled tree seedlings, saplings and trees at ten points using the point-centered quarter method (as in 1965–1966), where the stem is sampled that occurs nearest to a point in each of the four quadrats around the point. This was the method of choice for an expeditious survey of the forest in 1965–1966, but it is not the best method for assessing diameter growth, sapling survival or seedling success over time (permanent plots with marked stems would have been much more appropriate). It needs to be emphasized that the trees sampled in 1994 were not the identical trees sampled in 1965–1966—rather a random set of 40 trees (and saplings and seedlings) in the same stand was sampled in each period. The stands sampled were relatively homogeneous patches on uniform topography in a larger matrix of *P. radiata* forest. Ten quarter points were sampled in each stand, with four quadrats at each point for a total of 760 quadrats in the 19 stands. My intent was to sample live individuals of 40 trees, 40 saplings and 40 seedlings in the 40 quadrats of each stand, but in addition to live saplings I also sampled dead saplings in those stands with an unusually large number. The criterion for tree seedlings was a dbh less than 2.5 cm, for tree saplings a dbh 2.5 to 10 cm, and for trees a dbh more than 10 cm, all at 1.4 m above ground level. Any tree stem emerging at ground level or forking below 1.4 m height was considered an individual, even in multiple-stemmed *Q. agrifolia.* Tree height was measured with a clinometer. Tree seedlings were sparse in all stands and saplings were sparse in many stands, so search for them was extended only 30 m away from the points; area expands rapidly with distance away from the points, and so does the possibility of overlooking seedlings or small saplings. Where seedlings or saplings were not found within 30 m from a point, distance was recorded as 30 m for determining stand density; at this average distance with the point-centered quarter method, the calculated number of individuals per ha is 11. For species composition, quadrats with no seedlings or saplings within 30 m were considered unoccupied.

Annual rings were counted in 1965 on 26 fresh *P. radiata* stumps along a cleared powerline on Pebble Beach Properties, and in 1966 at a Carmel Valley sawmill on a deck of 41 *P. radiata* logs cut along Highway 1 over Carmel Hill.

In 1965–1966 small numbers of beef cattle (ca. 20) were observed on the properties encompassing six of the 19 relocated stands, but in 1994 cattle (small numbers again) were present in only two of the 19 stands.

RESULTS

Pinus radiata and *Q. agrifolia* were the only tree species recorded at the sample points in the 19 stands at Monterey in both 1965–1966 and 1994. (However, in 1965 a few individuals of *Pinus attenuata* Lemmon and *Pseudotsuga menziesii* (Mirbel) Franco were recorded at the sample points in one stand near Año Nuevo Pt.) Similarly, tree seedlings and saplings at the sample points in the 19 stands were all *P. radiata* or *Q. agrifolia,* except for three seedlings of *Arbutus menziesii* Pursh in 1965–1966 and one in 1994 and one sapling of *A. menziesii* in 1994.

Table 1 summarizes the measurements of trees, saplings, and seedlings from the 760 quadrats in the 19 stands relocated in 1994 and from the 760 quadrats in these same stands in 1965–1966. The only values significantly different over the time interval were the average number of trees per ha and the average dbh (Fig. 1). The average number of trees per ha decreased over the 28–29 yr interval; however, the average number per ha was nearly the same in 1994 (462) as in 1965–1966 (455) if five stands with unusually high numbers of trees per ha

TABLE 1. CHANGES IN 19 *P. RADIATA* STANDS FROM 1965-1966 TO 1994. Data from 760 quadrats in each time period.

	1965–1966	1994
Trees		
No. *P. radiata*	640	626
No. *Q. agrifolia*	120	134
Ave. No. per ha	636	460
Ave. stand dbh (cm)	34	40.2
Ave. *P. radiata* dbh (cm)	37.2	44.3
Ave. *Q. agrifolia* dbh (cm)	21.1	18.7
No. *P. radiata* 10–21 cm dbh	194	140
No. *P. radiata* 22–31 cm dbh	169	102
No. *P. radiata* >31 cm dbh	277	384
No. *P. radiata* >100 cm dbh	1	4
No. *Q. agrifolia* 10–21 cm dbh	87	97
No. *Q. agrifolia* 22–31 cm dbh	19	24
No. *Q. agrifolia* >31 cm dbh	14	13
No. *Q. agrifolia* >50 cm dbh	7	3
Tree seedlings		
Ave. No. per ha	160	252
No. *P. radiata*	118	229
No. *Q. agrifolia*	330	371
No. *A. menziesii*	3	1
No. occupied quadrats	451	601
Tree saplings		
Ave. No. per ha	177	99
No. *P. radiata*	328	324
No. *Q. agrifolia*	238	329
No. *A. menziesii*	0	1
No. occupied quadrats	566	654

(882 to 1359 in 1965–1966) (Figs. 2 and 3) are excluded. In 1965–1966, 78% of the 200 trees measured in these five stands were only 10–31 cm dbh, compared to 35% in 1994. All but three of the 200 trees in 1965–1966 were *P. radiata.* There was a 60% decrease, from 1148 to 461 in the average number of trees per ha in these five stands over the time interval.

The number of trees per ha in these "mature" *P. radiata* stands (excluding the five young stands with high numbers of poles per ha in 1965–1966) should reflect the highest natural stand density of *P. radiata* forests. The five stands with highest densities in the other 14 stands (of the 19) had an average of 575 trees per ha (512 to 646) in 1965–1966 and an ave of 641 (585 to 693) in 1994.

Average tree dbh increased slightly over the time interval but the measured average embraces several processes. Some trees grew in diameter during this time, but some died and their absence in 1994 would affect the average dbh. In 1965–1966 eight large, dead *P. radiata* snags were noted near the sample points, and 13 in 1994. Decay is rapid on these sites, so these numbers of snags are probably minimal. Disease, fire or perhaps some other factor could have killed these trees. The most susceptible to fire would have been young trees with thin bark and low canopies, but decay hides this evidence.

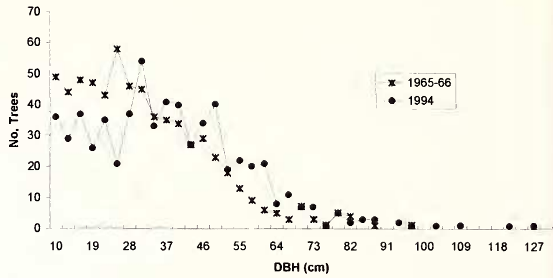

FIG. 1. Distribution of tree dbh, for *P. radiata* only, in all 19 stands. N-640 in 1965–1966, 626 in 1994.

Fire scars and/or charred bark on large *P. radiata* trees were noted in four of the 19 stands in 1965–1966, and in three different stands in 1994. *Fusarium subglutinans* (Wollenweb. and Reinking) Nelson, Toussoun, and Marasas (*F. moniliforme* J. Sheld. var *subglutinans* Wollenweb. and Reinking) (pine pitch canker) was just being noticed ca. 1994 on *P. radiata* in urban areas (=planted trees?) of the Peninsula, but was not apparent (i.e. canopies with dead needles) in my sample stands.

In addition, some saplings grew to tree size in the 28–29 yr period, lowering the average dbh. In 1994, 72% of *Q. agrifolia* trees were 10–21 cm dbh, a size that could easily have grown to trees from saplings in 1965–1966 and account for the slight measured decrease in *Q. agrifolia* average dbh over the time interval.

No annual rings were counted on trees or stumps of *P. radiata* in 1994. From rings counted in 1965–1966 on fresh stumps and logs, age is quite variable among trees with the same dbh. In the deck of 41 *P. radiata* logs, 24 to 44 rings were counted on 6 logs all 33 cm diameter, and 31 to 59 rings were counted on 6 logs all 61 cm diameter.

Tree sapling density was not significantly different between the two sampling periods, with density variable from 11 to 948 per ha in 1965–1966 and from 18 to 245 per ha in 1994. None of the 19 stands were grown to saplings in 1965–1966, rather I selected stands with tree-size individuals. Thus the sapling densities measured are low compared to densities occurring after hot fires. Many saplings die when pole size dbh is reached. To illustrate, the average dbh of *P. radiata* trees in the two stands with the smallest trees (all *P. radiata*) in 1965–

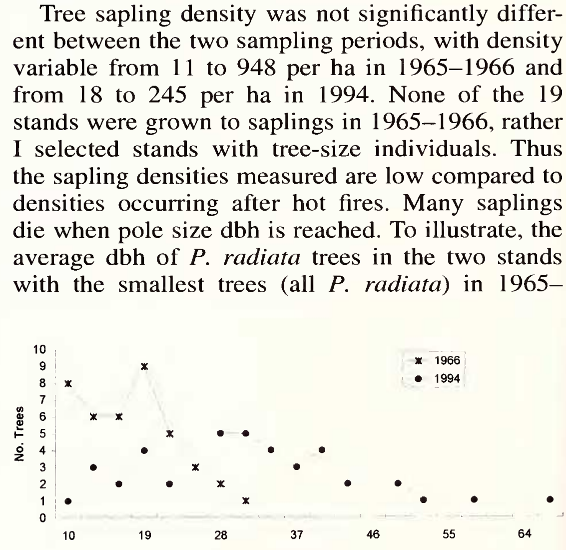

FIG. 2. Distribution of tree dbh in a young stand, all *P. radiata.*

FIG. 3. A 1994 view of the stand in Figure 2. Tree ht is ca. 18 m. This relatively young stand is located at ca. 215 m elevation on the east slope of the summit in the former Presidio of Monterey.

1966 was 19 and 20 cm. The number of saplings (all *P. radiata*) per ha in these two stands in 1965–1966 was 499 and 89. In the first stand 21 of the 40 quadrats were unoccupied by saplings and in the 19 quadrats with saplings 14 were deformed. The second stand had an unusually large number of dead saplings, 215 per ha. Thus it appeared that *P. radiata* sapling mortality occurred when average tree dbh reached somewhat less than 20 cm; from the available age-diameter data *P. radiata* trees at 20 cm dbh are approximately 20 to 25 yr old.

The proportion of saplings as *P. radiata* in all 19 stands did not change much over the time interval, at 58% in 1965–1966 and 50% in 1994, but the number of quadrats occupied by *Q. agrifolia* saplings increased by more than one-third.

Tree seedling density was not significantly different over the time interval, with density variable from 11 to 790 per ha in 1965–1966 and 15 to 986 in 1994. Seedling density appeared higher in 1994 than in 1965–1966 since the number of occupied quadrats increased by a third. Only one-fourth of the seedlings recorded in the 19 stands in 1965–1966 were *P. radiata,* and only one-third in 1994—the rest (except for four *A. menziesii*) were *Q. agrifolia.*

The *P. radiata* seedlings found in 1994 occurred in two sizes: 5–8 cm tall and 1–3 m tall (individuals taller than this have dbh in the sapling class i.e., 2.5 to 10 cm dbh, although a very few tall seedlings were measured at the sample points, four at 3 m height and two at 6 m). The shorter seedlings are probably several yr old, with root development as the major growth. Once a substantial root system has developed, shoot growth apparently proceeds rapidly which can account for the hiatus in height between the two sizes of seedlings. All *P. radiata* seedlings occurred with natural growth form, evidence that deer and cattle did not browse them.

Eight of the 19 stands in 1965–1966 had fewer than 17 tree seedlings per ha, and fewer than 13 quadrats were occupied by seedlings. Six of these eight stands had a dense, 1 to 1.5 m tall shrub cover of *Vaccinium ovatum* Pursh and/or *Arctostaphylos tomentosa* (Pursh) Lindley which could have limited sunlight for successful seedling establishment by *P. radiata.*

The 19 stands resampled in 1994 were far from being homogeneous. Some appeared to be pole stands originating after fire, while others were older stands with a wide range of tree dbh. Logged stands (previous to the 1965–1966 sampling) had an even wider range of tree dbh, skewed to larger trees and with numerous *Q. agrifolia* seedlings and saplings among and under the *P. radiata* trees. The average values in Table 1 mask obvious differences among the 19 stands, which can be arranged into groups based on the distribution of tree dbh. Three dissim-

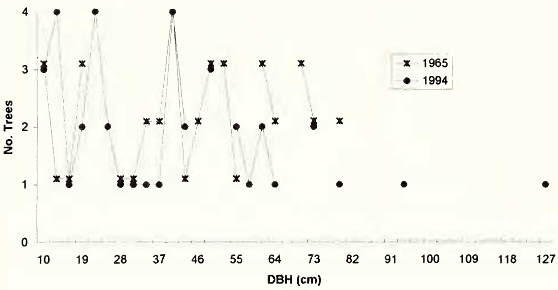

FIG. 4. Distribution of tree dbh in an old stand, nearly all *P. radiata* but with two *Q. agrifolia* in 1966 and three in 1996.

ilar stands will be used to emphasize the greatest differences.

In a young stand sampled in 1966 the average dbh for the trees (all *P. radiata*) was 20 cm and the distance measurements indicated a dense stand of 1200 trees per ha. Also present in 1966 were ca. 20 large, dead *P. radiata* trees per ha, all with charred bases; their presence suggests this was a stand of older trees that burned over in a hot fire. From my annual ring counts on logs and stumps the 20 cm dbh trees here were probably 20 to 25 yr old so this fire could have occurred in the early 1940's. By 1994 only 370 trees occurred per ha (Figs. 2 and 3), so major tree mortality occurred in the interval between sampling. There were 89 live *P. radiata* saplings per ha in 1966, but there also were 215 dead saplings per ha in 1966, indicating high mortality of *P. radiata* saplings at this early stage of stand development. One third of the 40 saplings in 1994 were *Q. agrifolia,* evidence that *Q. agrifolia* begins invasion of *P. radiata* stands in the early stages; they were sparse however, with only 30 per ha. There were practically no seedlings of either *P. radiata* or *Q. agrifolia,* with nearly all of the distances over 30 m in both 1966 and 1994 (i.e., no seedlings were found within 30 m from the quarter points). The dense shading cover of *Vaccinium ovatum* in this stand may have accounted for the low seedling density.

An older stand provides a second example of variation among the 19 stands. None of the trees sampled in 1966 in the young stand above were larger than 34 cm dbh, while in this older stand in 1965 dbh reached 84 cm (Figs. 4 and 5). The largest *P. radiata* sampled in all 19 stands in 1994 occurred here at 128 cm dbh. There were only 333 trees per ha in 1965, which contrasts with the 1200 per ha in the young stand above. Sapling density was low in 1965, at 25 per ha and consisted entirely of *P. radiata,* but increased to 73 per ha by 1994 with three of the 40 as *Q. agrifolia.* In 1965 there were 56 seedlings per ha in this stand, and most of them were *Q. agrifolia* (they were not seedlings of

FIG. 5. A 1994 view of the stand in Figure 4. This older stand is located at ca. 150 m elevation on an east-west ridge, 0.5 km southwest of Jacks Peak County Park.

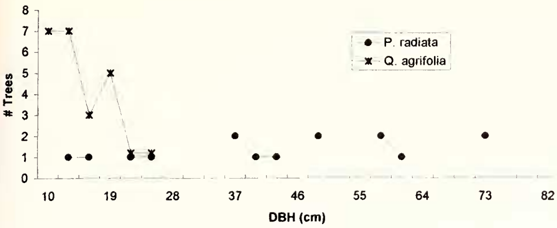

FIG. 6. Distribution of tree dbh in 1994 for 16 *P. radiata* and 24 *Q. agrifolia* from a stand logged prior to 1965.

a few yr, but rather browsed older bushes spreading laterally without any upright stem over 2.5 cm dbh). The canopy of this older stand on an east-west ridge top was apparently open enough for successful establishment of some *P. radiata* seedlings even without surface fire. By 1994 there were 359 seedlings per ha, all of them *P. radiata* (there were *Q. agrifolia* bushes still present, but at the higher density of the *P. radiata* seedlings *Q. agrifolia* individuals were not close enough to the sample points (=dense enough) to be recorded.

Another stand, apparently logged prior to sampling in 1965, provides a third example of variation among the stands. In contrast to the two previous stands, there were many *Q. agrifolia* trees present (Figs. 6 and 7). In 1965 11 of the 40 trees in the sample were small *Q. agrifolia* trees, with none larger than 14 cm dbh. In 1994, 24 of the 40 trees sampled were small *Q. agrifolia* trees, averaging 16 cm dbh with the largest at 23 cm. These *Q. agrifolia* trees were mostly multiple-stemmed, from the ground level. They accounted for the calculated high density of trees—1566 per ha in 1965 and 1340 in 1994. The *P. radiata* trees in this stand were large and sparse, so few were recorded at the sample points. In 1994 a second set of 40 trees were recorded, sampling only *P. radiata*. These measurements indicated a density of 171 *P. radiata* trees per ha with an ave dbh of 63 cm with the largest at 97 cm. These were tall, straight-trunked trees, without large, low spreading branches and there was no apparent reason for not having harvested them when the logging took place. Nearly all the saplings and seedlings at the sample points in this stand were *Q. agrifolia*, with 222 saplings and 49 seedlings per ha in 1994. *Pinus radiata* reproduction was poor under these small *Q. agrifolia* trees with their shading canopy and thick, persistent leaf litter. It seems likely that without a hot fire, *Q. agrifolia* will attain dominance in this stand.

DISCUSSION

Tree density and diameter. Mortality of young *P. radiata* is a probable cause for the decrease in tree

FIG. 7. A 1994 view of the logged (prior to 1965) stand in Figure 6, where *Q. agrifolia* is becoming dominant. The trunks of four remaining, sparse, large *P. radiata* trees ca. 23 m tall are visible. This stand is located on a north slope at ca. 135 m elevation, in Roach Canyon about halfway from Carmel Valley Road up to Jacks Peak.

density between 1965–1966 and 1994; subsequent fall-down and decay eliminates noticeable evidence. While some *P. radiata* poles may have died between 1965–1966 and 1994, the number of *P. radiata* trees over 31 cm dbh increased (Table 1). Observation did not reveal high mortality such as many dead snags among older *P. radiata* trees; widespread logging in the past undoubtedly removed many of the larger trees, leaving few to reach senescence by 1994.

Only five *P. radiata* trees over 100 cm dbh were found in the 19 stands. To emphasize the paucity of large trees in the contemporary *P. radiata* forests beyond the data in Table 1, the number of *P. radiata* over 100 cm dbh in the 29 other stands sampled in 1965–1966 was only 8 (out of 988 measured) and the number of *Q. agrifolia* trees over 50 cm dbh was only 6 (out of 166 measured). The two largest *P. radiata* trees measured by Jepson (1910) were 114 and 137 cm dbh. The oldest *P. radiata* tree cut in a 1946–1947 logging operation that felled nearly three million bd ft on the present Pebble Beach Properties was 70 yr, with an 81 cm dbh (Stoddard 1947). These measurements suggest that *P. radiata* attains a dbh of at least one m before senescence. The largest *P. radiata* trees in this study were open-grown with low spreading branches. The high incidence of knots from the retained lower branches may have been a reason for not harvesting these trees. The full-sun environment enabling them to attain their open-grown stature could have been due to intensive logging or to surface fires that thinned the adjacent trees.

Very few large *Q. agrifolia* trees occurred in the 19 stands (Table 1)—*P. radiata* forests are fire-prone and the thin bark of *Q. agrifolia* is a poor insulator. The largest *Q. agrifolia* tree found with a pronounced fire-scar occurred outside the sample stands with a dbh of 55 cm. The largest *Q. agrifolia* tree measured in the sampled stands was 88 cm dbh. Larger trees of *Q. agrifolia* commonly occur in canyon bottoms where the thick, moist, persistent leaf litter and shading canopy of *Q. agrifolia* are not conducive to spread of surface fire—the largest tree found (outside the sample stands) in a canyon bottom was 114 cm dbh.

Tree seedlings and saplings. Even though closed-cone *P. radiata* trees depend upon hot fires for a dense seed rain and a bare soil seed-bed, some cones open in ambient air temperatures giving a sparse seed rain in most years. Consequently, a few *P. radiata* seedlings are usually present even in the layer of persistent *P. radiata* needles and *Q. agrifolia* leaves. *Pinus radiata* seedlings often occur on ridge tops, where the litter layer is thinner and the topography apparently allows more sunlight at seedling level. Over time, low densities of *P. radiata* seedlings enter the sapling class, so that in effect an 'all-age' stand of *P. radiata* occurs even though the size-class distribution is markedly skewed to the trees that originated after the last hot fire.

With hot fires, closed-cone *P. radiata* trees shed a heavy seed rain onto bare soil and seedling germination and survival are excellent. After the 1959 and 1987 wildfires on the Huckleberry Hill area of the present Pebble Beach Properties, seedling densities appeared to me to be at least 100,000 per ha. Fenton (1951) recorded more than 2,400,000 seedlings per ha following fire in *P. radiata* forests in New Zealand. Jepson (1910) counted 612 four-yr old *P. radiata* seedlings on 100 sq ft of a burned stand in Pacific Grove; this converts to 658,500 per ha. The wildfires on Huckleberry Hill are the only hot fires that have occurred in the *P. radiata* forest in the past 40 yr. Larkey (1972) recorded hot fires on Del Monte Properties (now Pebble Beach Properties) in 1901 and 1905, but provided no location or size of area burned. More recently, wildfires in the *P. radiata* forests of the Monterey Peninsula have been prevented or rapidly controlled. I saw only one recent burn during 1965–1966, a fraction of one ha on private land, resulting in dense, 30–56 cm tall *P. radiata* seedlings after only one growing season (Vogl et al. 1977). In February of 1994 I saw only one recent burn, again on a tiny area, under a powerline on private land and with no vegetative recovery at the time. While fire scars and/or charred bark were noted in a few stands in both 1965–1966 and 1994, I could not ascertain the time of the fires producing these scars nor their effect on forest structure. The only contemporary prescribed burns under *P. radiata* on the Peninsula that I am aware are conducted in Point Lobos State Reserve; the management goal there, however, is to reduce *P. radiata* seedling and sapling density to produce more open forests (McGowan 1994).

Quercus agrifolia seedlings are common under *P. radiata* trees beyond pole size, easily tolerating the open shade. However, very few small, newly developed *Q. agrifolia* seedlings were present in the 19 stands. Instead, most common were short, spreading *Q. agrifolia* bushes due to repeated deer browsing and persisting for years. Without this browsing, growth would expectedly progress to the sapling and then tree stage, changing the stand composition to more *Q. agrifolia.* Even with the browsing, a central stem from the bush ultimately grows above the reach of deer and enters the sapling stage. The number of quadrats out of 760 occupied by *Q. agrifolia* saplings increased over the 28–29 yr—31% in 1965–1966 to 43% in 1994 (Table 1), increasing in 15 of the 19 stands.

The densities of *P. radiata* seedlings and saplings were very low in the 19 stands, compared to observed densities after the 1959 and 1987 crown fires. There may not be enough *P. radiata* reproduction to perpetuate these stands as *P. radiata* forests in the absence of hot fires, especially with the apparent increasing success of *Q. agrifolia* as the stands mature.

Stand age. Of the 626 *P. radiata* trees sampled in 1994, 12% were larger than 61 cm dbh. While the published *P. radiata* age-dbh data (Larsen 1932; Lindsay 1937; McDonald 1959) seems inadequate, some of it recorded 6–7 decades ago and based on small samples, the data indicate trees at 60 cm dbh are 65 to 100 yr old. Taking Roy's (1966) 80–90 yr ave life span for *P. radiata,* more frequent senescent trees might be expected soon in the *P. radiata* forests.

Conclusions

This study gave a measure of landscape development rate as forest acreage lost over time. Between 1965–1966 and 1994 four of the 38 stands sampled in 1965–1966 were removed by cutting for housing or a golf course. Five stands appeared to have been appreciably logged, but were still *P. radiata* forest. Three stands were destroyed by wildfire (although the dense reproduction of *P. radiata* seedlings following the fire in effect renewed these stands as *P. radiata* forests). Thus one-third of the 38 stands were seriously modified by human activity in the 28–29 yr interval (assuming the wildfire was human ignited). This degree of modification may not be representative since most of the 38 stands were some distance from the fringe of development.

Many of the 38 stands in 1965–1966 had low densities of *P. radiata* seedlings. In only 6 of these stands did this low density appear to be a consequence of dense, shading understory shrubs. The crowns of the *P. radiata* trees had abundant closed cones, and what seems needed is fire to open these cones for a seed rain and also to remove the litter exposing bare soil for successful seedling establishment.

The *P. radiata* forests are getting older. Only three of the 38 stands from 1965–1966 were "renewed" by fire by 1994, and the 1987 wildfire was an unintentional event. While low densities of *P. radiata* saplings did occur in the 19 stands sampled in 1994, I doubt that they occur in sufficient number to adequately perpetuate the stands in a condition similar to the *P. radiata* forests of today. With one-eighth of the *P. radiata* trees measured in 1994 over 61 cm dbh, which are ca. 65–100 yr old, senescence can be expected to increase soon in these stands.

The fate of the *P. radiata* forests on the Monterey Peninsula with complete fire control probably involves increasing dominance by *Q. agrifolia.* Logging of *P. radiata* appears to accelerate dominance by *Q. agrifolia.* It seems unlikely that hot fires can be used as a forest management tool on the Monterey Peninsula, a highly urbanized-recreational area. However even moderate, prescribed fires could probably injure or kill thin-barked *Q. agrifolia* saplings and young trees. With heavy deer browsing being the only apparent current yet ineffective limitation on *Q. agrifolia,* with continued logging of *P. radiata,* and without prescribed fires, the gradual increase in dominance by *Q. agrifolia* over time could change the character of the Peninsula from a *P. radiata* to a *Q. agrifolia* setting.

Acknowledgments

Both the 1965–1966 and 1994 studies of *P. radiata* forests were funded by the University of California, Hastings Natural History Reservation, Carmel Valley. Housing for the 1994 study was graciously provided by Karen and Hugo Ferlito of Carmel. My thanks to Dr. David Jowett for statistical advice and to Dr. Robin White for her critical review of the manuscript. Two anonymous reviewers made important suggestions for improving the manuscript. My wife Betty recorded the measurements in the field in 1994 and also, unfortunately, suffered from the ubiquitous *Rhus.*

Literature Cited

Cylinder, P. D. 1995. The Monterey ecological staircase and subtypes of Monterey Pine forest. Fremontia 23(1):7–13.

Deghi, G. S., T. Huffman and J. W. Culver. 1995. California's native Monterey pine populations: potential for sustainability. Fremontia 23(1):14–23.

Fenton, G. R. 1951. Regeneration of *Pinus radiata* D Don following fire. New Zealand Forest Service Forest Research Institute. Forest Research Notes 1(4):1–10.

Jepson, W. L. 1910. The Silva of California. Memoirs of the University of California. University of California Press, Berkeley, CA.

Larkey, F. B. 1972. Footnotes to the history of the Del Monte Forest. Pp. 45–48 *in* B. F. Howitt (ed.), Forest heritage—a natural history of the Del Monte Forest. California Native Plant Society, Berkeley, CA.

Larsen, L. T. 1915. Monterey pine. Society of American Foresters, Proc. 10(1):68–74.

Lindsay, A. D. 1932. Report on Monterey pine (*Pinus radiata* D. Don) in its native habitat. Commonwealth (Australia) Forestry Bureau, Bull. 10. (1937 reprint)

McDonald, J. B. 1959. An ecological study of Monterey pine in Monterey County, California. M.S. thesis, School of Forestry, University of California, Berkeley, CA.

McDonald, P. M. and R. J. Laacke 1990. *Pinus radiata.* Silvics of N.A., Vol. 1, Conifers. USDA Forest Service, Agric. Hdbk. 654.

McGowan, G. August 17, 1994. Personal communication. Supervising Ranger, Point Lobos State Reserve, Carmel, CA.

Pert, M. 1963. *Pinus radiata.* A bibliography to 1963 (Australian). Forestry and Timber Bureau, Canberra.

Roy, D. F. 1966. Silvical characteristics of Monterey pine (*Pinus radiata* D. Don) USDA Forest Service, Pacific SW Forest and Range Expr. Sta., Berkeley, CA. Res. Paper 31.

Scott, C. W. 1960. *Pinus radiata.* U.N. FAO Forestry and Forest Products Studies No. 14.

Stoddard, C. H. 1947. Forestry in the Monterey pines. American Forests 53(6):251, 275, 277.

Vogl, R. J., K. L. White, W. P. Armstrong and K. L. Cole. 1977. The closed-cone pines and cypress. Pp. 295–358 *in* M. G. Barbour, and J. Major (eds.), Terrestrial Vegetation of California. Wiley and Sons, Inc. New York.